PATENT APPLICATION

Magnetic Recording Medium
and Magnetic Recording Apparatus

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Magnetic Recording Medium and Magnetic Recording Apparatus

Background of the Invention

[0001]

1. Field of the Invention

The present invention relates to a magnetic recording apparatus, and to a magnetic recording medium particularly used for a magnetic recording apparatus.

[0002]

2. Description of Related Art

The rapidly growing IT industry increases the demand for magnetic disc units with a larger capacity than ever before. This demand stimulates the development of a highly sensitive magnetic head and a recording medium with a high S/N ratio. For improving S/N ratio of a recording medium, the recording medium should have an improved retrieving output for high-density recording. In general, a recoding medium is composed of a substrate, a first underlayer (called a seed layer), a second underlayer made of Cr-based alloy which has a body-centered cubic structure, a magnetic layer, and a carbon protective layer, which are sequentially formed one over another. The magnetic layer is formed from a Co-based alloy of hexagonal close-packed structure, such as CoCrPtB and CoCrPtTa. Improvement in retrieving output is accomplished if the magnetic layer has its (11·0) or (10·0) plane oriented approximately parallel to the substrate surface so that the c-axis (which is the

easy axis of magnetization) coincides with the longitudinal
direction of the magnetic layer. It is known that the
crystal orientation in the magnetic layer is determined by
the seed layer. There are reports saying that the (11·0)
plane orients as desired if the seed layer is formed from
Ta (which is disclosed in Japanese published applications
JPA 4-188427, JPA8-212531 and Japanese patent JP3298893) or
MgO (disclosed in Appl. Phys. Lett., vol. 67, pp. 3638-3640,
December (1993)) and that the (10·0) plane orients as
desired if the seed layer is formed from NiAl ally of B2
structure (disclosed in Japanese patent JP5693426).
Moreover, it is known that improvement in retrieving output
is achieved if the substrate surface is mechanically
texturized so that anisotropic magnetization takes place in
the circumferential direction. Texturizing used to be
applied mostly to an Al-Mg alloy substrate coated with an
NiP plating film. However, texturizing is also applied to
a glass substrate to create magnetic anisotropy (disclosed
in Japanese published application JPA 2001-209927).
[0003]

Not only improvement in retrieving out but
reduction in medium noise is also important for the medium
to have a high S/N ratio. Reduction in medium noise is
effectively accomplished if the magnetic layer is formed
from finer particles or the magnetic layer has a smaller
value of $B_r·t$, which is the product of the remanent

magnetic flux density (B_r) of the magnetic layer and the thickness (t) of the magnetic layer. However, noise reduction in this manner is limited because an extreme reduction in particle size or $B_r \cdot t$ value aggravates thermal stability. There has recently been proposed an antiferromagnetically coupled recording medium which achieves noise reduction without adverse effect on thermal stability (disclosed in Appl. Phys. Lett., vol. 77, pp. 2581-2583, October (2000)and Appl. Phys. Lett., vol. 77, pp. 3806-3808, December (2000)). This magnetic recording medium has two magnetic layers which are antiferromagnetically coupled to each other, with an Ru intermediate layer interposed between them. As compared with the recording medium of single-layer magnetic layer, it has a lower $B_r \cdot t$ value while the magnetic layer remains thick. This is the reason why it has a reduced noise level while keeping good thermal stability.

[0004]

Notwithstanding the foregoing technologies combined together, it is still impossible to realize an areal recording density in excess of 70 megabits/mm^2 and it is necessary to further improve retrieving output and to further reduce medium noise.

Accordingly, what is needed is a recording medium with high S/N ratio, which has high recording density and at the same time reliable.

[0005]

Summary

In a preferred embodiment, the invention provides a magnetic disk drive capable of high recording density. In accordance with one aspect of the present invention, a magnetic recording medium has a high medium S/N ratio and remains sufficiently stable to thermal fluctuation. The invention also provides a highly reliable magnetic recording apparatus which achieves an areal recording density in excess of 70 megabits/mm^2 when said magnetic recording medium is used for recording and retrieving under optimal conditions in combination with a highly sensitive magnetic head.

[0006]

The present invention to attain the above-mentioned object is directed to a longitudinal recording medium which comprises a non-magnetic substrate and a magnetic layer formed thereon with three underlayers interposed between them, said magnetic layer being composed of a plurality of layers of Co-based alloy of hexagonal close-packed structure which are antiferromagnetically coupled to one another through a non-magnetic intermediate layer, said three underlayers including a first one of amorphous alloy, a second one of Ta, and a third one of Cr-based alloy of body-centered cubic structure.

[0007]

The present invention is based on the inventors'
finding that a recording medium has a strong (11·0)
orientation if it is composed of a substrate and a magnetic
layer formed thereon, with a first underlayer of amorphous
alloy, a Ta layer, and a Cr alloy layer interposed between
them. The present invention is also based on the
inventors' finding that the magnetic recording medium
constructed as mentioned above exhibits strong magnetic
anisotropy in the circumferential direction if the magnetic
layer is formed on a substrate whose surface is texturized
in the circumferential direction. The amorphous alloy for
a first underlayer should be one which is composed of Co as
the principal component and at least one element selected
from Zr, Ta, Nb, Ti, W, Mo, B, and Si in a total amount no
less than 5 at%(which stands for atom percent) and no more
than 60 at%, one which is composed of Ni as the principal
component and at least one element selected from Ta, Nb, Zr,
Ti, and P in a total amount no less than 5 at% and no more
than 60 at%, one which is composed of Cr as the principal
component and at least one element selected from Ti, Zr, Ta,
B, and Si in a total amount no less than 5 at% and no more
than 60 at%, or one which is composed of at least one
element selected from Nb, Zr, Ta, Mo, and Ti as the
principal component and Si in an amount no less than 5 at%
and no more than 50 at%. The alloy is referred to as
amorphous if it gives an X-ray diffraction pattern lacking

distinct diffraction peaks except for halo patterns or if it is composed of fine particles having an average particle diameter no larger than 5 nm which is obtained from the lattice fringe image photographed under a high-resolution electron microscope. The content of additional elements should be within the specified range; otherwise, the amorphous alloy tends to become crystalline. In the case of an amorphous alloy for a first underlayer which is composed mainly of Co, it may be incorporated with Cr, V, or Mn so as to reduce or prevent its magnetization. Any other alloy than mentioned above may be used for a first underlayer so long as it has the amorphous structure. An alloy of B2 structure (such as Ni-50 at% Al), which is not amorphous, may also be used for a first underlayer. It produces the same effect as the amorphous alloy. A first underlayer mentioned above is coated with a second underlayer of Ta so that a third underlayer formed thereon from Cr-based alloy of body-centered cubic structure orients in the (100) direction. The Ta film should be 1-10 nm thick for its strong orientation. The tendency toward orientation can be enhanced if the surface of the Ta layer is artificially oxidized in oxygen or oxygen-argon mixture after layer formation.

[0008]

The material for a third underlayer is not specifically restricted so long as it is an alloy of body-

centered cubic structure composed mainly of Cr, such as CrTi, CrMo, and CrW. It is also possible to form a third underlayer from two or more layers of these alloys. CrTiB alloy for a third underlayer is particularly preferable because it permits the magnetic layer to be composed of fine particles, which contributes to reduction in medium noise.

[0009]

The magnetic layer may be composed of a magnetic layer (or a lower magnetic layer) adjacent to the substrate and a magnetic layer (or an upper magnetic layer) adjacent to the protective layer, said two magnetic layers being antiferromagnetically coupled to each other, with an intermediate layer of Ru interposed between them. The upper and lower magnetic layers are not specifically restricted so long as they are formed from a Co-based alloy of hexagonal closed-pack structure. Moreover, the magnetic layer may be composed of three or more layers of Co-based alloy, with a non-magnetic intermediate layer interposed between them. The non-magnetic intermediate layer is not specifically restricted so long as it is formed from a non-magnetic material.

[0010]

The substrate may be a glass substrate, an Al-Mg alloy substrate coated with NiP plated film, or a ceramic substrate. Texturizing to form concentric grooves on the

surface of the substrate causes the magnetic layer to have a coercive force which is larger in the circumferential direction than in the radial direction. This contributes to the output resolution. Texturizing may be performed on the surface of the substrate either directly or indirectly after a first or second underlayer has been formed.

[0011]

The above-mentioned magnetic recording medium is combined with a compound-type magnetic head including a recording magnetic head of electromagnetic induction type and a retrieving magnetic head of spin valve type so as to provide a highly reliable magnetic recording apparatus having an areal recording density in excess of 70 megabits/mm^2, to which the present invention is also directed.

Other aspects and advantages of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention.

Brief Description of the Drawings

[Fig. 1]

Fig. 1 is a schematic diagram showing one example of the sectional structure of the magnetic recording medium according to the present invention.

[Fig. 2]

Fig. 2 is a hysteresis curve of the recording

medium according to one embodiment of the present invention.

[Fig. 3]

Fig. 3 is an X-ray diffraction spectrum of the recording medium according to one embodiment of the present invention.

[Fig. 4]

Fig. 4 is an X-ray diffraction spectrum of a first underlayer used in one embodiment of the present invention.

[Fig. 5]

Fig. 5 is a histogram showing the distribution of the particle diameters of particles constituting the magnetic layer in one embodiment of the present invention.

[Fig. 6]

Fig. 6 is a graph showing the change with time of retrieving output which is observed in the recording medium according to one embodiment of the present invention.

[Fig. 7]

Fig. 7 is a perspective view showing one example of the magnetic recording apparatus according to the present invention.

[Fig. 8]

Fig. 8 is a perspective view showing one example of the sectional structure of the magnetic head used in the magnetic recording apparatus according to the present invention.

[Fig. 9]

Fig. 9 is a schematic diagram showing one example of the sectional structure of the magneto-resistive sensor of the magnetic head used in the magnetic recording apparatus according to the present invention.

[0012]

Description of Illustrative Embodiments

The examples of the invention will be explained below with reference to the accompanying drawings.

Example 1

The magnetic recoding medium as one example of the present invention has a sectional structure shown in Fig. 1. It includes a substrate 10 of aluminosilicate glass with a chemically reinforced surface and several layers formed thereon in the following manner. On the substrate, which has been cleaned with alkali and dried, are formed at room temperature a first underlayer 11 of Ni alloy (30 nm thick) and a second underlayer 12 of Ta (2 nm thick). The Ni alloy is Ni-45 at% Ta, Ni-35 at% Nb, Ni-35 at% Zr, Ni-20 at% P, Ni-50 at% Ti, or Ni-20 at% Cr-10 at% Zr. With the substrate heated at about 240°C by a lamp heater, a third underlayer 13 (10 nm thick) is formed from Cr-15 at% Ti-5 at% B alloy. On the top of the underlayers are sequentially formed a lower magnetic layer 14 (3.8 nm thick) of Co-16 at% Cr-6 at% Pt alloy, an intermediate magnetic layer 15 (0.6 nm thick) of Ru, and an upper magnetic layer 16 (17.2 nm thick) of Co-18 at% Cr-12 at%

Pt-8 at% B alloy. The top of the magnetic layers is covered with a carbon protective layer 17 (3.2 nm thick). Finally, the protective layer is coated with a lubricant composed mainly of perfluoroalkylpolyether which forms a lubricant layer 18 (1.8 nm thick). Incidentally, the above-mentioned multilayered films were formed by using a single-wafer sputtering apparatus (MDP 250B) available from Intevac Corporation. The sputtering apparatus was evacuated to 1.0-1.2 × 10^{-5} Pa and run so that the cycle time was 9 seconds. Sputtering was carried out in argon at 0.93 Pa to form all the layers except for the carbon protective film, which was formed in argon containing 10% nitrogen.

[0013]

Table 1

Sample No.	First underlayer	H_c (kA/m)	$B_r \cdot t$ (T-nm)	H_x (kA/m)	Resolution (%)	Normalized noise (mV_{rms}/mV_{pp})	Medium S/N (dB)
101	Ni-45Ta	303	4.1	53	51	0.0342	23.5
102	Ni-35Nb	275	4.2	52	54	0.0388	22.9
103	Ni-35Zr	309	4.1	50	51	0.0395	22.2
104	Ni-20P	291	4.3	53	53	0.0397	22.5
105	Ni-30Ti	312	4.0	52	52	0.0367	23.0
106	Ni-20Cr-10Zr	317	3.9	49	51	0.0398	22.2

Composition in terms of atomic%.

[0014]

This example gave samples of the recording medium which possess the magnetic characteristics and recording-retrieving characteristics as shown in Table 1. The

magnetic characteristics were evaluated at room temperature by using a vibrating sample magnetometer (VSM), with a magnetic field (796 kA/m at maximum) applied in the circumferential direction. The recording-retrieving characteristics were evaluated by using a compound head including a GMR head and a writing head, the former having a shield gap length (Gs) of 94 nm and a read track width (Twr) of 320 nm, the latter having a gap length (Gl) of 140 nm and a track width (Twr) of 420 nm. As a result, any medium had a coercive force of 270 kA/m or more. The recording medium designated as sample No. 101 gave a magnetization curve as shown in Fig. 2. It should be noted that the curve has a step which indicates that the lower magnetic layer undergoes magnetization reversal when the applied magnetic field exceeds about 53 kA/m. The magnetic field (indicated by point P in the figure) that gives rise to the step is defined as the coupled magnetic field (H_x). All the samples in this example gave positive values of H_x. This suggests that the upper magnetic layer and the lower magnetic layer are antiferromagnetically coupled to each other and that magnetization of the lower magnetic layer (in the state of remanent magnetization) is antiparallel to magnetization of the upper magnetic layer. The foregoing leads to a conjecture that the recording medium in this example has the remanent magnetization $B_r \cdot t$ which is represented approximately by $B_r \cdot t = B_{r1} \cdot t_1 - B_{r2} \cdot t_2$, where B_{r1}

and t_1 denote respectively the remanent magnetic flux density and film thickness of the upper magnetic layer, and B_{r2} and t_2 denote respectively the remanent magnetic flux density and film thickness of the lower magnetic layer. In addition, the samples in this example exhibit very good recording-retrieving characteristics, with a medium S/N higher than 22 dB. It is worth noting that the sample in which the first underlayer is formed from Ni-Ta alloy exhibits a low normalized noise whereas the sample in which the first underlayer is formed from Ni-P alloy or Ni-Nb alloy exhibits a high resolution. The normalized noise herein is defined as NdHF/So, where NdHF denotes the medium noise which results from recording at the maximum linear recording density of 24.8 kFC/mm (631 kFCI) and So denotes the isolated read pulse output. The resolution herein is defined as SMF/So, where SMF denotes the read output which results from the linear recording density of 12.4 kFC/mm (which is half the maximum linear recording density) and So denotes the isolated read pulse output. The medium S/N is defined as $20 \cdot \log(\text{SMF/NdHF})$.

[0015]

The recording medium (designated as sample No. 101) gave an X-ray diffraction pattern shown in Fig. 3. The X-ray diffractometry was carried out with $CuK_{\alpha 1}$ lines. It is noted that the X-ray diffraction pattern has a peak in the neighborhood of $2\theta = 73°$, which is attributable to the

(11·0) plane in the magnetic layer. A probable reason for this is that the magnetic layer has epitaxially grown on the Cr-Ti-B underlayer orienting in the (100) direction. The X-ray diffraction pattern has a very weak peak due to the (200) plane of the Cr-Ti-B underlayer, because this underlayer is as thin as 10 nm. For comparison, the same X-ray diffractometry as above was performed on a single-layer film (30 nm thick) formed at a room temperature from the Ni-45 at% Ta (which was used to form the first underlayer in the above-mentioned medium). The resulting X-ray diffraction pattern is shown in Fig. 4. The pattern has a broad halo peak at $2\theta = 40-43°$. This suggests that the Ni-Ta alloy layer is of amorphous structure. Other recording media in this example all give the identical diffraction patterns, which indicates that their magnetic layer orients in the (11·0) direction and their first underlayer is of amorphous structure.

[0016]

The recording medium designated as sample No. 101 was examined for particles constituting its magnetic layer by observation under a transmission electron microscope (TEM) in the following manner. First, the surface lattice image is photographed with a magnification of about ×2,000,000, and the area of each crystal grain is calculated. One domain in which lattice stripes orient in the same direction is regarded as one crystal grain, and

any crystal grain assuming the bicrystal structure (in which the adjacent c-axes are mutually perpendicular) is regarded as consisting of different crystal grains. Then, the profile of each crystal grain is hypothetically transformed into a complete circle equal in area, and the diameter of the circle is measured. The thus measured diameter is defined as the particle diameter of individual crystal grains. About 300 crystal grains are measured for particle diameter as mentioned above, and the arithmetic average of measured values is regarded as the average particle diameter. The particle diameters thus measured have a distribution represented by a histogram in Fig. 5. The average particle diameter is as small as 8.9 nm, and the standard deviation normalized with respect to the average particle diameter is 28%, which suggests a uniform variance of particle diameters.

Comparative Example 1

Samples of recording media each having two underlayers were prepared as follows by repeating the procedure of Example 1. The process was started with cleaning and drying an aluminosilicate glass substrate. On the glass substrate was formed at room temperature a first underlayer of Ta (5-30 nm thick) or Ni-45 at% Ta (30 nm thick). With the substrate heated at about 240°C by a lamp heater, a second underlayer of Cr-15 at% Ti-5 at% B was formed. After that, a magnetic layer and a carbon

protective layer were sequentially formed, which are
identical in composition and thickness to those in Example
1.

[0017]

Table 2

Sample No.	First underlayer	H_c (kA/m)	$B_r \cdot t$ (T-nm)	H_x (kA/m)	Resolution (%)	Normalized noise (mV_{rms}/mV_{pp})	Medium S/N (dB)
111	Ta (30 nm)	281	3.9	57	47	0.0417	21.0
112	Ta (20 nm)	278	4.0	52	48	0.0422	21.1
113	Ta (10 nm)	243	4.1	46	51	0.0477	20.6
114	Ta (5 nm)	209	4.1	39	51	0.0542	19.6
115	Ni-45Ta (30 nm)	309	4.0	50	48	0.0417	21.2

Composition in terms of atomic%.

[0018]

The comparative samples were examined for magnetic
and recording-retrieving characteristics in the same way as
in Example 1. The results are shown in Table 2. It is
noted that those samples having a first underlayer formed
from Ta (but lacking a first underlayer specified in
Example 1) increase in both coercive force and medium S/N
in proportion to the thickness of Ta underlayer. However,
they are inferior in both magnetic and recording-retrieving
characteristics to those samples in Example 1. This is
true even for sample No. 113 which is best. On the other
hand, sample No. 114, which has a first underlayer of Ni-Ta
as with sample No. 101 in Example 1 but lacks a second
underlayer specified in Example 1, is almost comparable in
coercive force to sample No. 101 but is poor in resolution

and lower in medium S/N by 2 dB or more.

Example 2

Samples of recording media were prepared by coating a glass substrate (having its surface concentrically texturized) with three underlayers, two magnetic layers, and a carbon protective film sequentially formed thereon. A first underlayer (20 nm thick) was formed from any of Co-30 at% Cr-12 at% Zr, Co-30 at% V-12 at% Ta, Mo-30 at% Si, Nb-20 at% Si, Zr-15 at% Si, Cr-20 at% Zr, Cr-20 at% Ti, Cr-10 at% B, Ta-30 at% Si, and Ti-30 at% Si. A second underlayer (3 nm thick) was formed from Ta. With the substrate heated at 280°C by a lamp heater, a third underlayer (8 nm thick) was formed from Cr-20 at% Ti-3 at% B. The magnetic layers were constructed in the same way as in Example 1.

[0019]

Table 3

Sample No.	First underlayer	H_{cc} (kA/m)	H_cOR	H_x (kA/m)	Resolution (%)	Normalized noise (mV_{rms}/mV_{pp})	Medium S/N (dB)
201	Co-30Cr-12Zr	292	1.09	48	52	0.0401	22.3
202	Co-30V-12Ta	287	1.15	52	53	0.0422	22.0
203	Mo-30Si	311	1.08	47	51	0.0415	21.8
204	Nb-20Si	324	1.05	48	49	0.0402	21.7
205	Zr-15Si	321	1.07	44	50	0.0408	21.8
206	Cr-20Zr	302	1.09	51	51	0.0425	21.6
207	Cr-20Ti	282	1.14	51	52	0.0419	21.9
208	Cr-10B	305	1.09	47	51	0.0412	21.9
209	Ta-30Si	318	1.06	54	49	0.0405	21.7
210	Ti-30Si	320	1.06	53	50	0.0410	21.7

Composition in terms of atomic%.

[0020]

The samples in this example were examined by X-ray diffractometry. As with sample No. 101 in Example 1, they all gave diffraction peaks due to the (11·0) plane of the magnetic layer and broad halo patterns due to the first lower underlayer. Table 3 shows the magnetic and recording-retrieving characteristics of the samples in this example. H_cOR is defined as H_{cc}/H_{cr}, where H_{cc} denotes the coercive force which is measured when a magnetic field is applied in the circumferential direction and H_{cr} denotes the coercive force which is measured when a magnetic field is applied in the radial direction. The samples were also tested for recording-retrieving characteristics by using a head in which Twr is 200 nm and Tww is 270 nm. All the

samples gave an H$_c$OR value higher than 1.05. This suggests that they have magnetic anisotropy introduced in the circumferential direction. The samples Nos. 201, 202, 206, 207, and 208 in which the first underlayer is formed from Co or Cr-based alloy are characterized by high H$_c$OR values and a resolution higher than 51 %. Also, the samples Nos. 203, 204, 209, and 210 in which the first underlayer is formed from Si-containing alloy are characterized by low normalized noise and good medium S/N higher than 21.7 dB although they have rather low H$_c$OR values.

Comparative Example 2

The same procedure as in Example 2 was repeated with the same equipment to produce samples of recording media having the same layer construction and composition, except that a first underlayer on the substrate is a single-layer film (30 nm thick) formed at room temperature from any of Zr, Ti, Mo, W, Cr, and V. This underlayer gave an X-ray diffraction pattern having one or more sharp peaks, suggesting that it is crystalline. Each sample of recording media thus obtained underwent X-ray diffractometry. The samples in which the first underlayer is formed from Ti, W, or V gave a diffraction pattern having peaks due to the (11·0) plane, (10·0) plane, and (00·1) plane of the magnetic layer. By contrast, the samples in which the first underlayer is formed from Zr, Cr, or Mo gave a diffraction pattern having only one peak due

to the (11·0) plane of the magnetic layer. However, the
peak intensity is lower by 30-50% than that of the sample
in Example 2. The samples in this comparative example are
much lower in H_{cc} values than those in Example 2, as noted
from Table 4. Presumably, this is because the magnetic
layer has a weak orientation in the (11·0) direction, as
mentioned above. In addition, the samples in this
comparative example also have H_cOR values lower than 1.05,
which suggests that anisotropy in the circumferential
direction is not effectively introduced. For this reason
they are low in resolution and they are also lower in
medium S/N by 2-3 dB than the samples in Example 2.
Incidentally, the sample No. 212 (in which the first
underlayer was formed from Ti) gave too low a retrieving
output to permit the measurement of recording-retrieving
characteristics.

[0021]

Table 4

Sample No.	First underlayer	H_{cc} (kA/m)	H_cOR	H_x (kA/m)	Resolution (%)	Normalized noise (mV_{rms}/mV_{pp})	Medium S/N (dB)
211	Zr	273	1.02	51	46	0.0489	19.5
212	Ti	121	1.01	12	--	--	--
213	W	195	1.02	23	41	0.0486	18.5
214	Mo	254	1.04	20	45	0.0465	19.7
215	Cr	268	1.03	27	46	0.0491	19.4
216	V	196	1.04	22	42	0.0504	19.4

[0022]

Example 3

Samples of recording media were prepared in the following manner. An Al-Mg alloy substrate coated with an NiP plating film was concentrically texturized. On the substrate (heated at 280°C) was formed a first underlayer (60 nm thick) from any of Ni-50 at% Al, Ni-50 at% Ti, Fe-50 at% Al, Fe-50 at% Ti, Fe-50 at% V, Co-50 at% Fe, Co-50 at% Ti, Co-50 at% Zr, Co-50 at% Al, Ru-50 at% Al, Mn-50 at% Al, and Mn-50 at% V. This underlayer was formed in two stages (for 30 nm thick each) by using two chambers. On the first underlayer were sequentially formed a second underlayer (5 nm thick) of Ta, an alloy layer (15 nm thick) of Cr-30 at% Mo-3 at% B, an alloy layer (3 nm thick) of Co-37 at% Cr, a magnetic layer, and a protective film. The magnetic layer is composed of a first magnetic layer (5 nm thick) of Co-19 at% Cr-10 at% Pt-4 at% B, an intermediate layer (0.7 nm thick) of Ru, and a second magnetic layer (22 nm thick) of Co-16 at% Cr-12 at% Pt-5 at% B-2 at% Cu.

[0023]

Each sample was tested for magnetization, with a magnetic field applied in the circumferential direction. The H_x was found to be 40-55 kA/m from the magnetization curve. This suggests the presence of antiferromagnetic coupling between the first and second magnetic layers. Table 5 shows magnetic properties and recording-retrieving characteristics.

[0024]

Table 5

Sample No.	First underlayer	H_{cc} (kA/m)	H_cOR	$K_u \cdot v/kT$	Medium S/N (dB)
301	Ni-50Al	334	1.15	87	22.5
302	Ni-50Ti	321	1.06	94	21.9
303	Fe-50Al	318	1.15	90	22.0
304	Fe-50Ti	325	1.13	92	21.9
305	Fe-50V	333	1.14	88	22.3
306	Co-50Fe	307	1.16	90	21.7
307	Co-50Ti	311	1.10	88	21.6
308	Co-50Zr	318	1.09	87	22.2
309	Co-50Al	317	1.14	99	22.0
310	Ru-50Al	329	1.21	102	22.4
311	Mn-50Al	325	1.31	105	22.2
312	Mn-50V	316	1.11	95	22.3

Composition in terms of atomic%.

[0025]

In Table 5, $K_u \cdot v/kT$ is a parameter defined as follows.

K_u : constant of magnetocrystalline anisotropy

v : volume of magnetic crystal grain

k : Boltzmann constant

T : absolute temperature

As shown in cf. J. Magn. Magn. Mater. 127, p. 233 (1993), it was obtained from Sharrock's formula to which was fitted the time dependence of residual coercive force at room temperature in a period ranging from 7.5 to 240 seconds. The present inventors' investigation revealed that if the thus obtained parameter has a value larger than about 85, then the magnetic recoding medium is free from output decrease

due to thermal fluctuation and hence is sufficiently
reliable. The samples of recording media all have Ku·v/kT of
85 or more, which is sufficiently stable for thermal
fluctuation. Moreover, good medium S/N higher than 21.7 dB
was obtained.

Example 4

Samples of recording media were prepared in the
following manner. A substrate of soda lime glass with a
chemically reinforced smooth surface was prepared. On the
substrate (heated at 100°C) was formed a first underlayer
(22 nm thick) from any of Co-30 at% Cr-8 at% Nb, Co-30 at%
Cr-10 at% Ti, Co-30 at% Cr-8 at% W, Co-34 at% Mn-12 at% Mo,
Co-34 at% Mn-10 at% B, Co-10 at% V-8 at% Si, Cr-40 at% Ta,
and Cr-15 at% Si. Further, a second underlayer (4 nm
thick) was formed from Ta. With the first and second
underlayers formed thereon, the substrate was removed from
the vacuum chamber and had its surface concentrically
texturized. The substrate was placed again in the vacuum
chamber and heated to 220°C by means of a lamp heater. On
the substrate were sequentially formed an alloy layer (5 nm
thick) of Cr-10 at% Ti-7 at% B, an alloy layer (5 nm thick)
of Cr-20 at% W, a magnetic layer (specified below), and a
carbon protective film (4.5 nm thick). The magnetic layer
is composed of a first magnetic layer (4 nm thick) of Co-15
at% Cr-8 at% Pt-10 at% B, a second magnetic layer (4 nm
thick) of Co-15 at% Cr-8 at% Pt-10 at% B, and a third

magnetic layer (24 nm thick) of Co-18 at% Cr-12 at% Pt-6 at% B-2 at% Cu. These magnetic layers are separated from each other by an intermediate layer (0.7 nm thick) interposed between them.

[0026]

Table 6

Sample No.	First underlayer	H_{cc} (kA/m)	H_cOR	Medium S/N (dB)	Rate of output decrease (%)
401	Co-30Cr-8Nb	348	1.22	21.6	0.92
402	Co-30Cr-10Ti	351	1.31	22.0	0.75
403	Co-30Cr-8W	333	1.28	21.5	0.95
404	Co-34Mn-12Mo	345	1.25	21.8	0.81
405	Co-34Mn-10B	339	1.28	21.4	0.85
406	Co-10V-8si	342	1.27	21.3	0.99
407	Cr-40Ta	346	1.33	21.9	0.81
408	Cr-15Si	344	1.35	22.4	0.76

Composition in terms of atomic%.

[0027]

It is noted from Table 6 that all the samples in this example gave H_{cc} values higher than 330 kA/m and H_cOR values higher than 1.2. The samples in this example have higher H_cOR values than those of Example 2 in which the glass substrate has its surface directly texturized. This suggests that texturizing that is performed after the underlayer has been formed is more effective in increasing the H_cOR values. In addition, the samples in this example all gave good medium S/N (higher than 21.6 dB) measured in the same way as in Example 2. Fig. 6 shows how the sample No. 401 changes in retrieving output with time. This data

was obtained by measuring signal strength continuously over a period of 1000 seconds after recording at a linear recording density of 15.7 kFC/mm on the recording medium placed in a thermostat at 65°C. It is noted that the rate of decrease in retrieving output in the case of sample No. 401 is 0.95% per exponent. Other samples also gave a rate of decrease in retrieving output smaller than 1% per exponent. This result suggests that the samples in this example are thermally stable.

Example 5

Each of the samples Nos. 101, 201, 204, 208, 209, 301, 310, and 401 in Examples 1 to 4 was incorporated into the magnetic recording apparatus shown in Fig. 7. This apparatus comprises a magnetic recording medium 91, a drive unit 92 to drive it, a magnetic head 93 including a recording part and a retrieving part, a means 94 to move the magnetic head relative to the magnetic recording medium, a signal processing means 95 for input to and output from the magnetic head, and a mechanism 96 for the magnetic head to retract at the time of unloading.

[0028]

The magnetic head is constructed as schematically shown in Fig. 8 (perspective view). It is a compound head including a recording head of electromagnetic induction type and a retrieving head of magneto-resistive effect type, both formed on a substrate 801. The recording head

includes an upper recording magnetic pole 803 and a lower

recording magnetic pole (functioning also as an upper

shield layer) 804, with a coil 802 interposed between them.

These recording magnetic poles are separated from each

other by a gap of 120 nm. The coil is formed from 1.5-μm

thick copper film. The retrieving head includes a magneto-

resistive sensor 805 and two electrode patterns 806 placed

at both sides thereof. The magneto-resistive sensor 805 is

held between the upper shield layer 804 (functioning also

as the lower recording magnetic pole) and the lower shield

layer 807. These shield layers are 80 nm apart from each

other. There is a gap layer between the recording magnetic

poles, and there is also a gap layer between the shield

layer and the magneto-resistive sensor; however, these gap

layers are omitted in Fig. 8.

[0029]

The magneto-resistive sensor has a sectional

structure as shown in Fig. 9. It has a signal detecting

region 900 which includes a plurality of conducting

magnetic layers and a magneto-resistive sensor (or

retrieving element of spin valve type which is placed

between the conducting magnetic layers. The conducting

magnetic layers relatively change in their respective

magnetization directions in response to the external

magnetic field, thereby producing a large resistance change.

The magneto-resistive sensor has a gap layer 901, a Ta

buffer layer 902, a lower magnetic layer 903, a copper
intermediate layer 904, an upper magnetic layer 905, and an
antiferromagnetic layer 906 of Pt-Mn alloy, which are
sequentially formed one over another. The lower magnetic
layer is formed from Ni-20 at% Fe alloy and the upper
magnetic layer is formed from cobalt. The upper magnetic
layer is fixedly magnetized in one direction owing to the
exchange magnetic field from the antiferromagnetic layer.
In contrast, the lower magnetic layer, which is in contact
with the upper magnetic layer with a non-magnetic layer
interposed between them, varies in its direction of
magnetization due to leakage magnetic field from the
magnetic recording medium, and this gives rise to
resistance change. The signal detecting region has its
both ends tapered. The tapered parts 907 have a pair of
permanent magnet layers 908 (which make the lower magnetic
layer single domain structure) and a pair of electrodes 806
to take out signals which are formed on the permanent
magnet layers 908. The permanent magnetic layer is formed
from Co-Cr-Pt alloy so that it has a large coercive force
and remains stable in the direction of easy magnetization.

[0030]

The magnetic head used in this example is that of
magneto-resistive effect type which is formed on a magnetic
head slider weighing 2 mg or less and having a flying
surface rail area smaller than 1.4 mm^2. The magnetic head

as specified above has improved shock resistance as well as high recording density. In fact, it realized a mean time between failures (MTBF) longer than 300,000 hours for a recording density higher than 70 megabits/mm^2.

[0031]

From the foregoing it will be appreciated that the embodiments as disclosed above has an improved medium S/N ratio as well as good thermal stability. When combined with a magnetic head of magneto-resistive effect type, it permits an areal recording density exceeding 70 megabits/mm^2 with an MTBF longer than 300,000 hours.